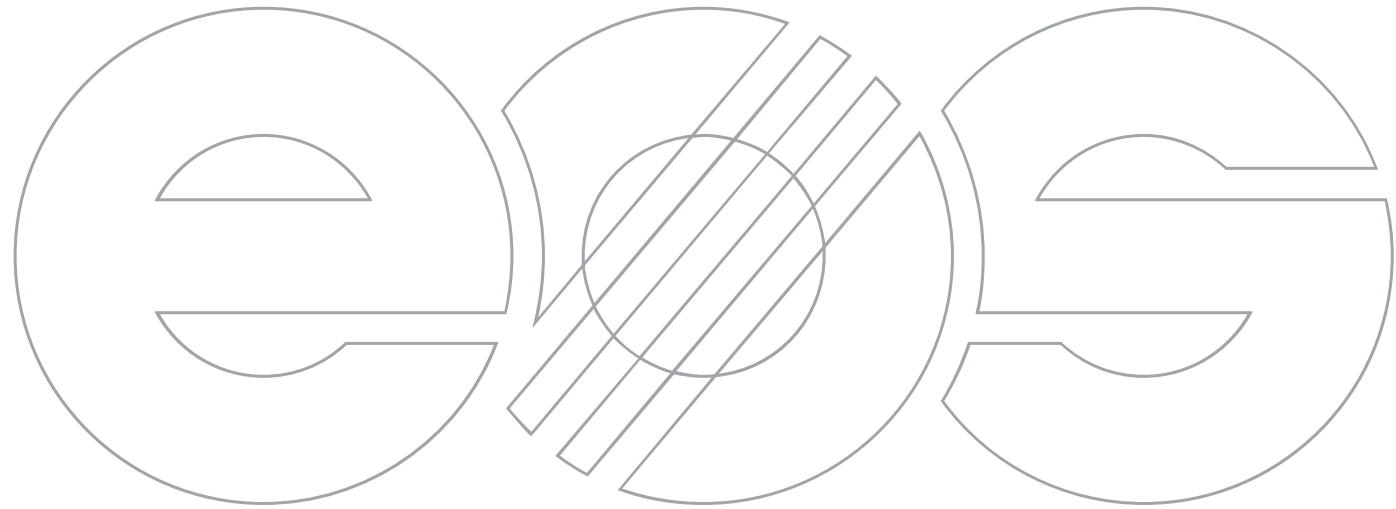# Design for Research

A Case Study of Building a Research Metal 3D Printer

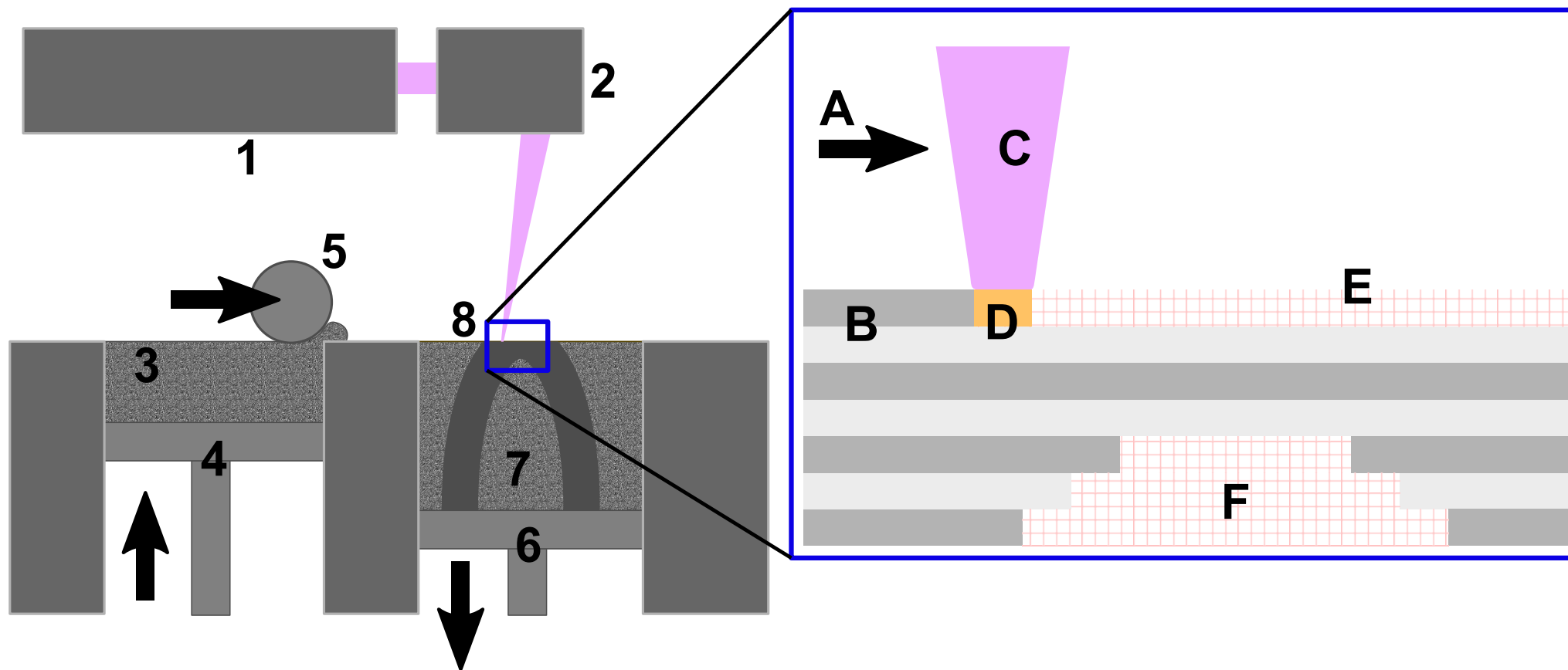**Damien F. Gray**, PhD

Principal Laser Optics Engineer

Agenda

- Project overview

- Philosophy

- Steps

- Execution

- Results

- Lessons Learned

Project Overview – Powder Bed Fusion Metal 3D Printer

Project Overview - Extras

➢ Process monitors

    ➢ Laser melt pool monitor

    ➢ Part bed temperature monitor

    ➢ Short feed monitor

➢ Process control

    ➢ Feedback control of laser power

    ➢ Synchronized laser control

    ➢ Automated laser and galvo calibration

➢ Safety

    ➢ Passivation of metal powder in gas filters

    ➢ Powder always under inert gas

Philosophy

➢ No compromises

➢ Generic core appropriate to problem

➢ Modular, loosely coupled design

➢ Documented interfaces

➢ Incremental progress

Steps – Normal R&D

1. Gather the requirements
2. Design infrastructure that will support all the requirements
3. Build infrastructure hardware and code
4. Test
5. Fix the problems until it works

6. Design minimal working hardware and code
7. Build hardware and code
8. Test
9. Fix the problems and find new requirements
10. Build the missing but already designed infrastructure
11. Repeat steps 6-10 *ad infinitum…*

Execution

> Requirements gathered

> Slow speed controller

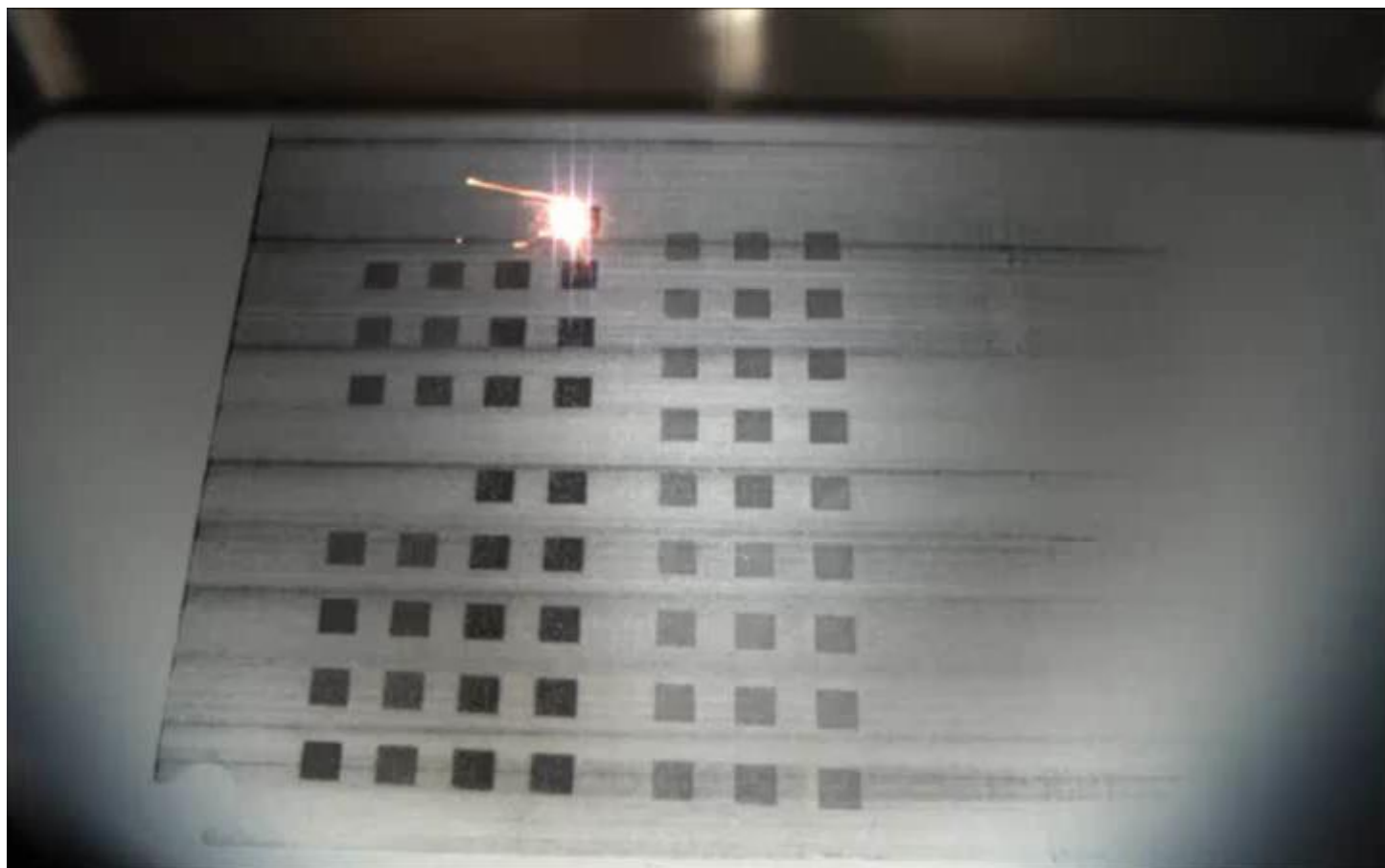> Fast controller

> Good processor for managing 3D files

> Hardware chosen

> Standard PC running Windows 7 for slow control

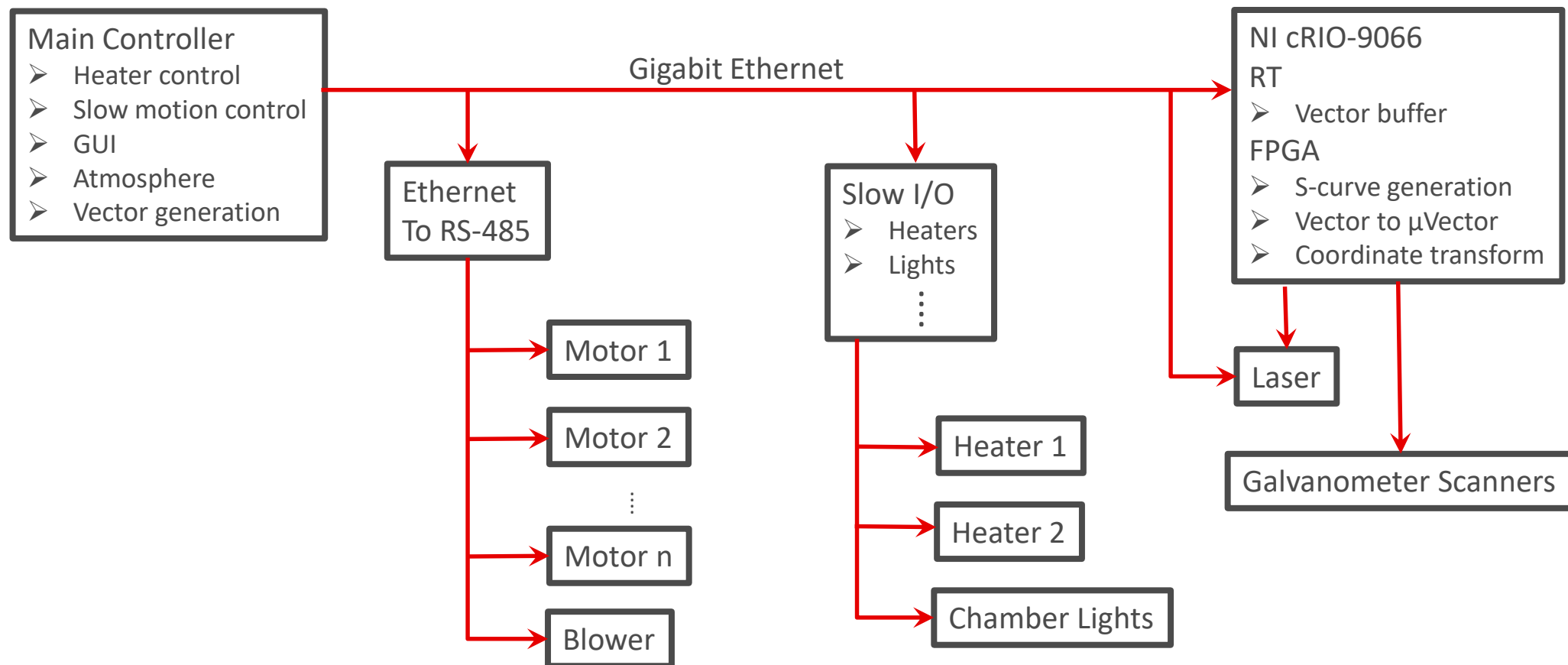> NI cRIO-9066 with I/O for fast control

> Software platforms chosen

> C# for slow control and GUI

> LabVIEW RT and FPGA for fast control

Six Months Later…

Basic Machine Architecture

Main Controller
- Heater control
- Slow motion control
- GUI
- Atmosphere
- Vector generation

Gigabit Ethernet

Ethernet
To RS-485

Slow I/O
- Heaters
- Lights
⋮

NI cRIO-9066
RT
- Vector buffer
FPGA
- S-curve generation
- Vector to µVector
- Coordinate transform

Motor 1

Motor 2
⋮
Motor n

Blower

Heater 1

Heater 2

Chamber Lights

Laser

Galvanometer Scanners

Laser and Scanner Calibration

Focus

- Biggest priority
- Dynamic as focus conditions change depending on part bed location
- Manual first
- Automation never completed

XY position

- Required for accurate parts
- Traditionally done by burning fiducials in a stable substrate followed by digitizing and image analysis
- Implemented by scanning fiducials on a calibration plate utilizing simultaneous scanning and data collection

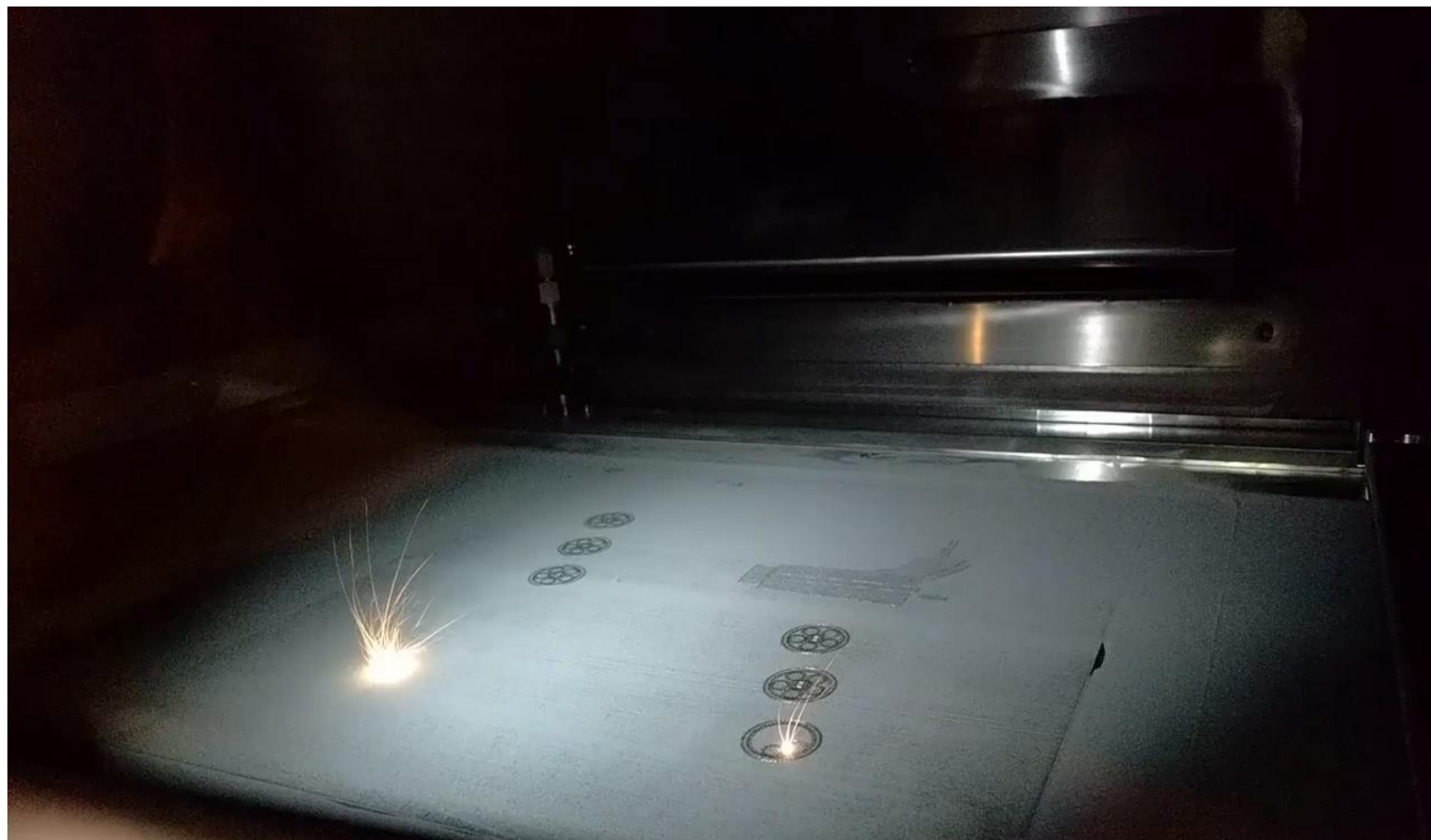## Laser Power

- Simple manual procedure, never automated

Motors Do Not Work

➢ Initial model of the motor did not have the control accuracy needed

➢ Traced problems to both motors and drivers

➢ Required rewrite of motion actor to support new controller

➢ Seamless interchange in software

More Functionality

- Slicer support to build actual 3D models
- Synchronization delays in laser and galvo data pipeline
- GUI as a separate process (enables remote GUI)
  - Main controller GUI model is a message transceiver

- Simulators for all devices (enables better debugging)
- Driver support for multiple laser, galvanometer scanner, and motion stage manufacturers
- cRIO changed for sbRIO with custom daughterboard on one machine for better I/O
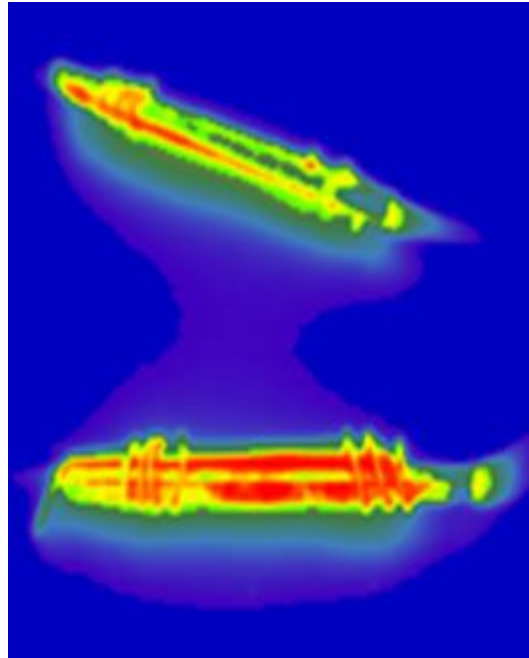
Fully Working Basic Machine
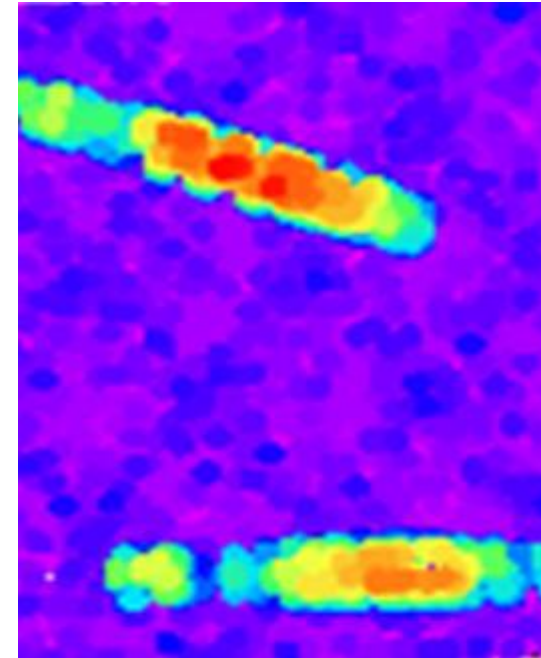
Let's Do Melt Pool Monitoring

➢ One week for first signal in the lab

➢ Two weeks for signals displayed on the GUI
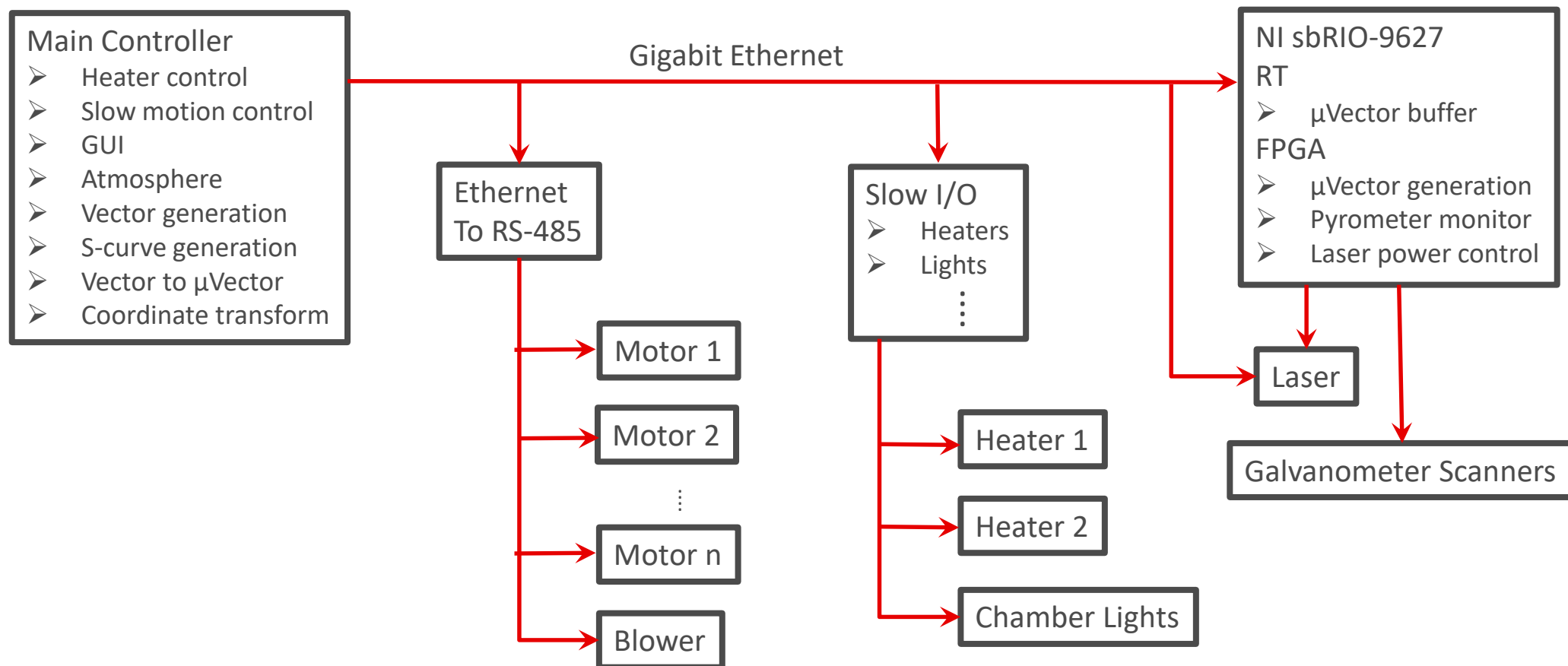

Tubular Heater Test Setup

IR Camera Display

Inline Pyrometer Display

Let's Do Melt Pool Laser Power Control

➢ PID control of laser based on pyrometer signal added to FPGA

➢ Ran out of fabric in FPGA

➢ Moved motion generation to the main controller

➢ Refactored RT/FPGA to be a much simpler buffer

➢ Better performance and more flexibility

New Machine Architecture

Let's REALLY Do Melt Pool Laser Power Control
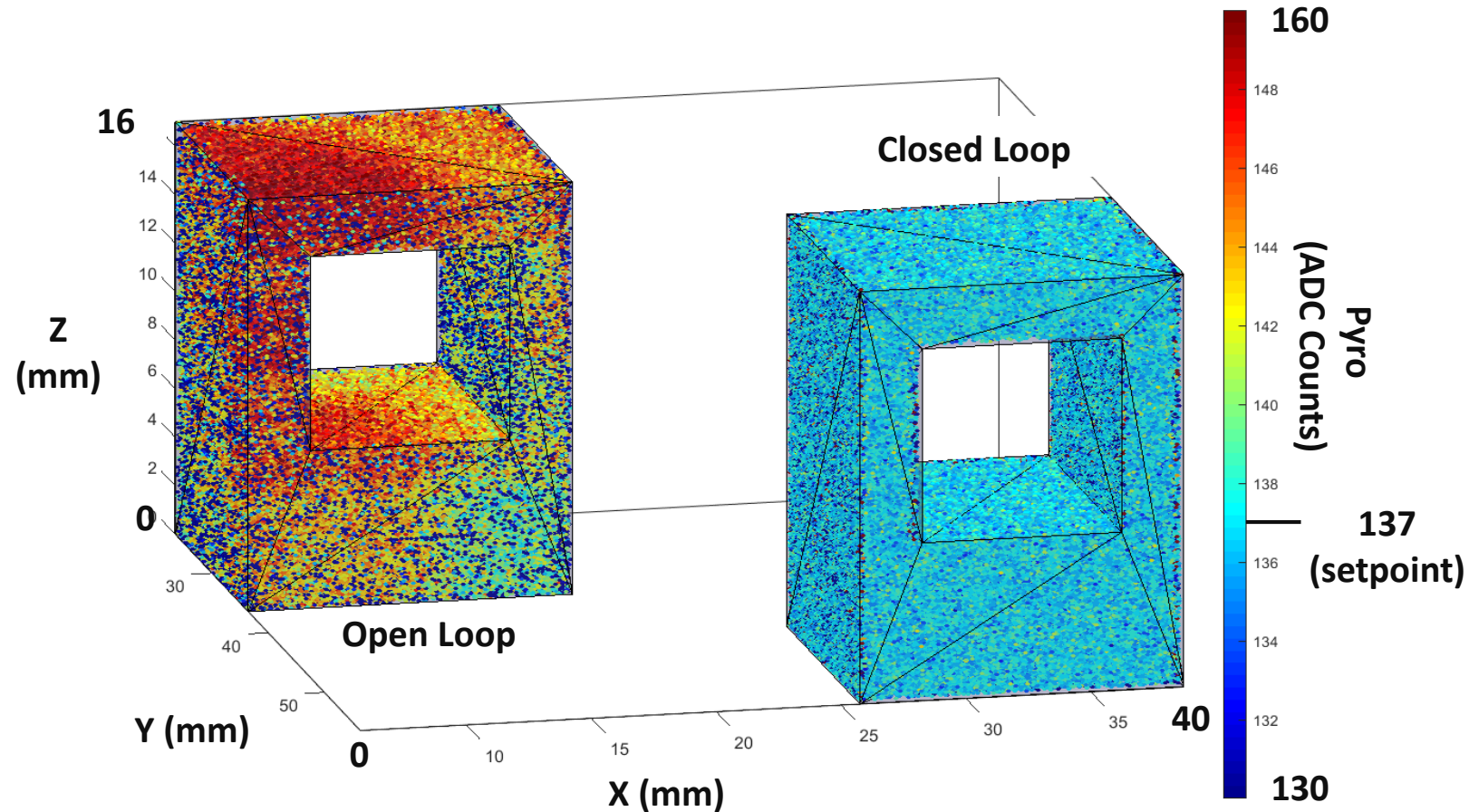
That's All (for now…)

Blueprint for R&D Success

➤ Plan for what you want, not what you think you can get

➤ Use a generic core appropriate to your problem

  ➤ Make your infrastructure strong

  ➤ Fix your infrastructure promptly when problems arise

➤ Use a modular, loosely coupled design

➤ Document your interfaces

➤ Make incremental changes

Questions?